Dark Matter Search Status from DEAP-3600

WNPPC 2026

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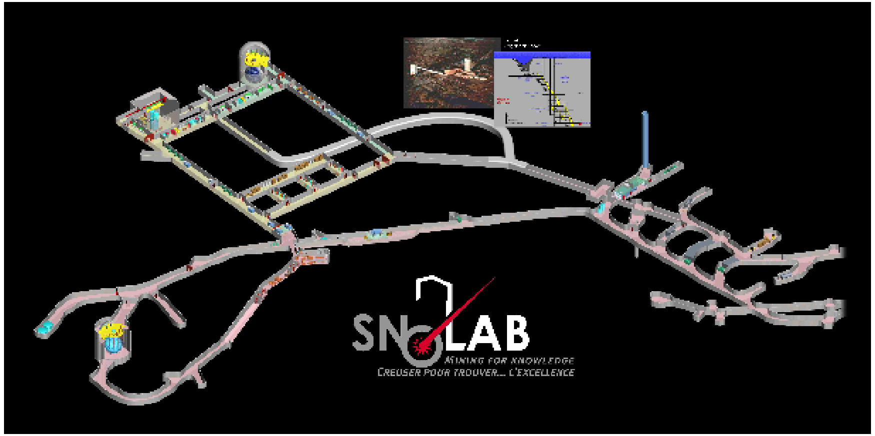
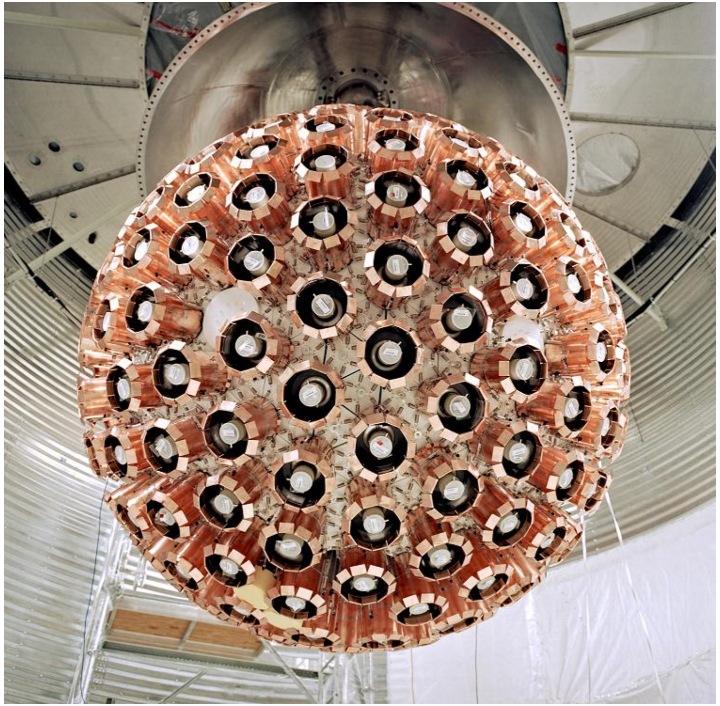
DEAP-3600

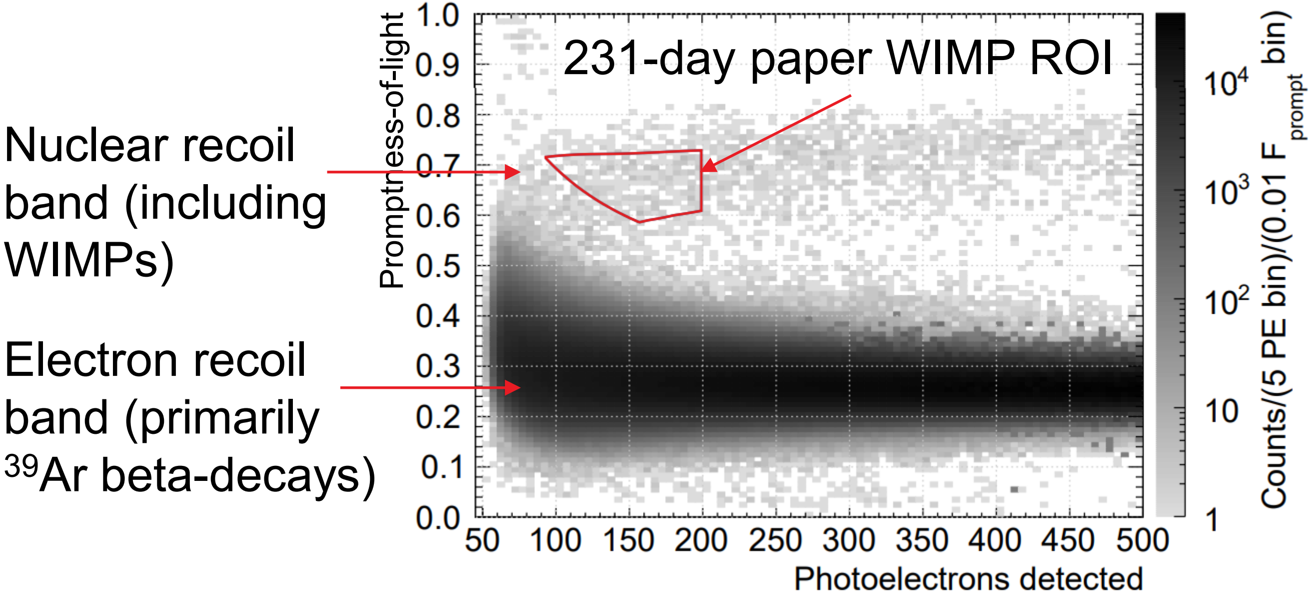
- Located ~2 km underground at SNOLAB.
- Single-phase, spherical liquid argon dark matter direct detection experiment.
- Please see Jie Hu's poster for more information.





Pulseshape Discrimination

- The dominant background in our detector is ^{39}Ar beta-decays.
- A nuclear recoil event, such as from weakly interacting massive particles (WIMPs) hitting an argon nucleus, produces scintillation light more promptly than ^{39}Ar beta-decays.



- This difference allows us to define a region of interest (ROI) that reduces the dominant ^{39}Ar background to negligible levels.

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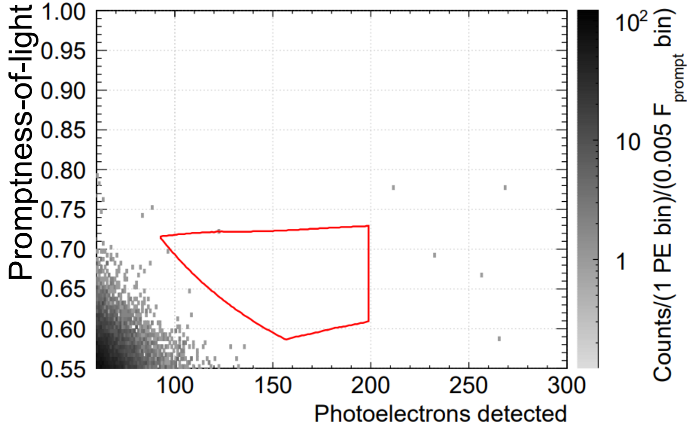
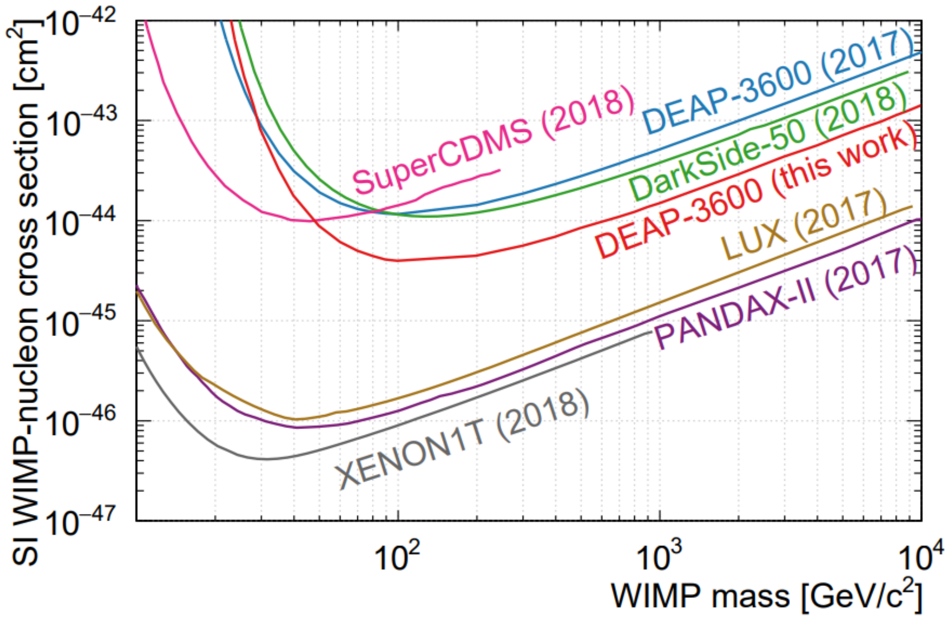
WIMP Search

Previous Results: 231 Live-day WIMP Dark Matter Search

arxiv:1902.04048

- Zero events were detected within our ROI.
  - The total background estimate in our ROI was 0.62 events in the 231 live-day dataset.





- An upper limit of 3.9×10^{-45} cm^2 at the 90% C.L. was placed on the WIMP-nucleon cross-section at a WIMP mass of 100 GeV.

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WIMP Dark Matter Search Using a Profile Likelihood Ratio

- A new WIMP exclusion curve is nearing completion using a profile likelihood ratio.

Test Statistic: $\lambda = \frac{\mathcal{L}\left(\mu,\hat{\hat{\theta}}\right)}{\mathcal{L}(\hat{\mu},\hat{\theta})}$

Fixed WIMP cross-section, maximum likelihood estimators for all nuisance parameters.

Floating WIMP cross-section, maximum likelihood estimators for all nuisance parameters.

- Compared to our 231 live-day search, this WIMP search will have:
  - More data (~791 live-days).
  - Updated background models.
  - Increased WIMP acceptance from loosened cuts.
  - A profile likelihood ratio approach.

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Profile Likelihood Ratio

Test Statistic: $\lambda = \frac{\mathcal{L}\left(\mu,\hat{\hat{\theta}}\right)}{\mathcal{L}\left(\hat{\mu},\hat{\theta}\right)}$

Fixed WIMP cross-section, maximum likelihood estimators for all nuisance parameters.

Floating WIMP cross-section, maximum likelihood estimators for all nuisance parameters.

μ: WIMP cross-section.
θ: "Nuisance parameters." These are parameters that need to be included in the likelihood fit but are not the parameter of interest.

- Neyman-Pearson's lemma states that the most powerful test statistic when performing a test between a null and alternate hypotheses comes from the ratio of the likelihoods of the alternate hypothesis to the likelihood of the null hypothesis.
- In other words, a profile likelihood ratio produces the optimal WIMP cross-section exclusion limit that can be set with our dataset.

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The Likelihood Function

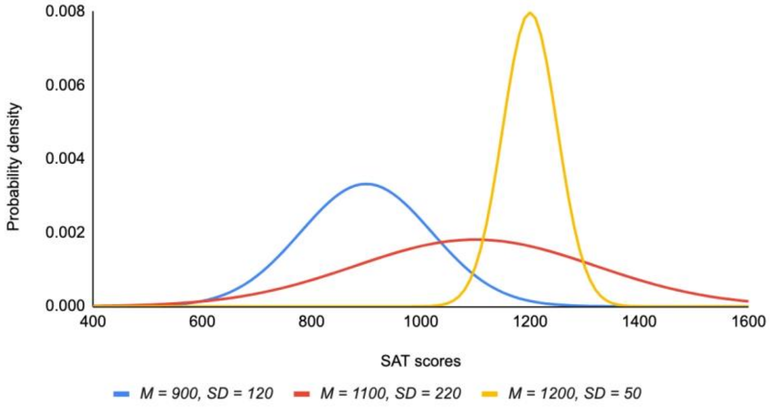
- The likelihood function defined in our analysis consists of two terms:
  - A model term that evaluates the probability that an observed event is any of our backgrounds or a WIMP.
  - A constraint term that incorporates our uncertainty on each nuisance parameter.

$$\mathcal{L}(\mu|\{\theta\}) = \mathcal{L}_{\mathrm{Model}}(\mu|\{\theta\}) \cdot \mathcal{L}_{\mathrm{constraint}}(\{\theta\})$$

Probability Density Functions

- For each event type considered in the analysis we develop a model that describes the energy, radial position, and promptness-of-light of events of that type. We use probability density functions (PDFs) to do this.
- These variables are not independent, so 2D models need to be created to capture the relationship between energy and the other two variables.
- The PDFs are used in evaluating the model term shown on the previous slide.

Example for Illustration



- The PDFs need to be distinct from each other, otherwise the likelihood fit will have no power to distinguish between different event types.

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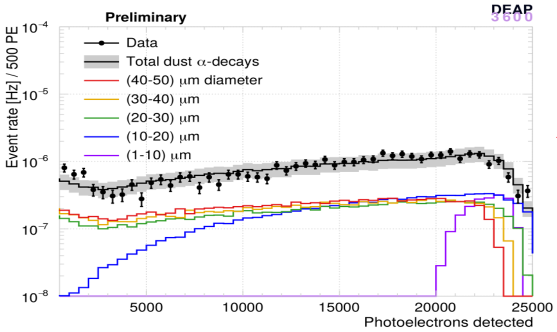
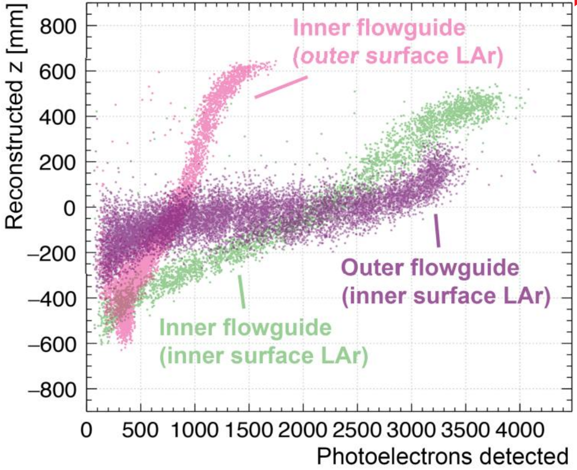
Updated Models





- Models have been produced for all major backgrounds within our ROI.
  - Dust alphas: ^{210}Po α-decays coming from dust within the liquid argon.
  - Shadowed alphas: ^{210}Po α-decays produced in the neck of the detector.
  - Surface alphas: ^{210}Po α-decays originating on the inner surface of the detector.
  - Radiogenic Neutrons: Neutrons primarily coming from the glass of the photomultiplier tubes.
  - ^{39}Ar: Beta decays of ^{39}Ar, constituting the largest source of background within the detector but removed from the ROI through pulse-shape discrimination.
- Additionally, a background estimate on Cherenkov radiation from the acrylic of the DEAP detector and the PMT glass has been calculated.
- Both ^{39}Ar and Cherenkovs are determined to be negligible within our WIMP ROI.

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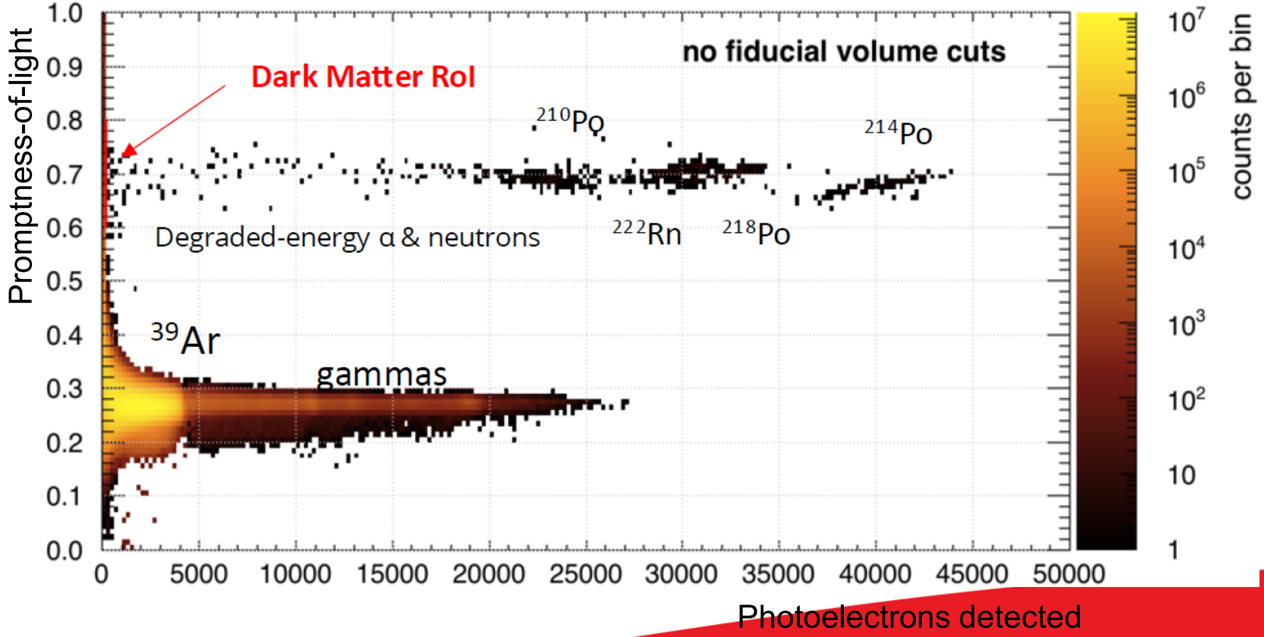
Backgrounds: Dust Alphas

- The primary background within the WIMP ROI is from ^{210}Po α-decays from metallic dust floating in the liquid argon. These alpha particles attenuate within the dust before reaching the liquid argon, reducing the energy of the detected event. This allows dust alphas to appear within the WIMP ROI.



Phys. Rev. Lett. 121, 071801 (2018) arXiv:1707.08042

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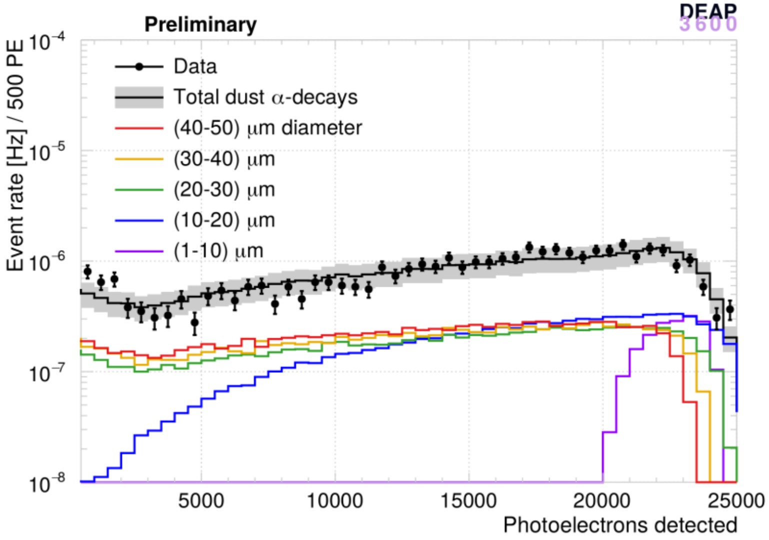
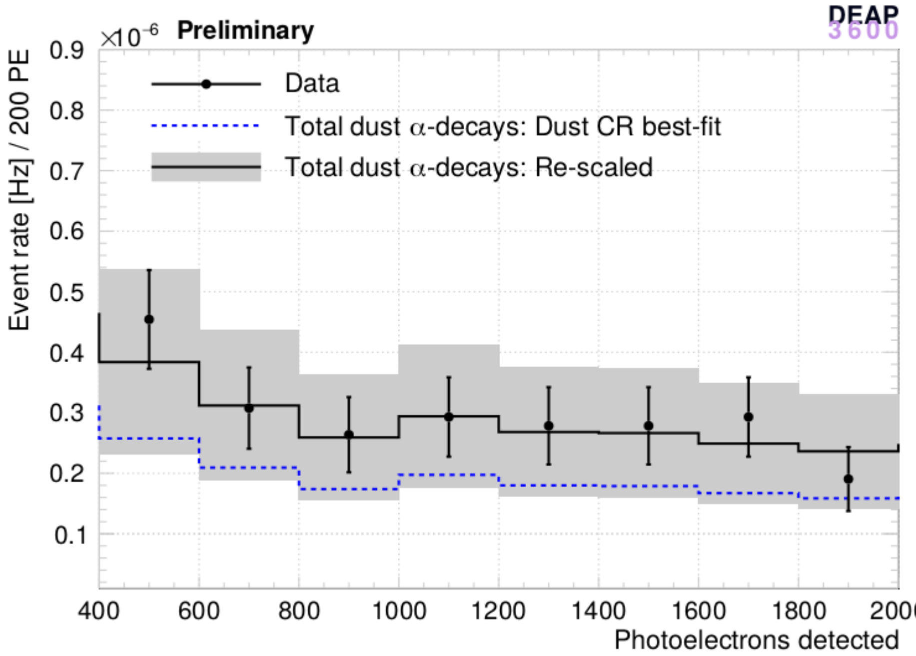
Backgrounds: Dust Alphas

- The size of the dust particles is fit using data in a high-energy dust control region. Additionally, the dust may have been partially coated in the wavelength shifter on the inner surface of the DEAP detector.





- There is systematically more data than dust at energies immediately above the WIMP ROI. A correction has been applied by fitting the overall dust rate to data in a dust control region sideband.
- No other known background contributes to this region.

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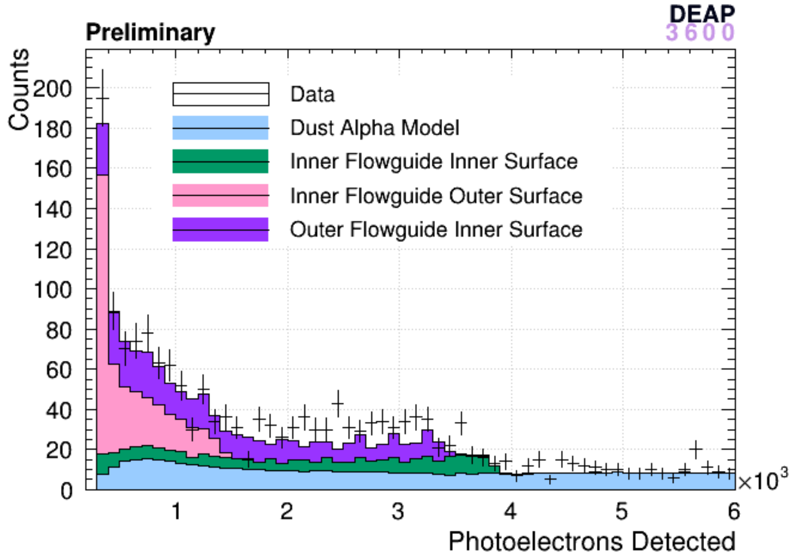
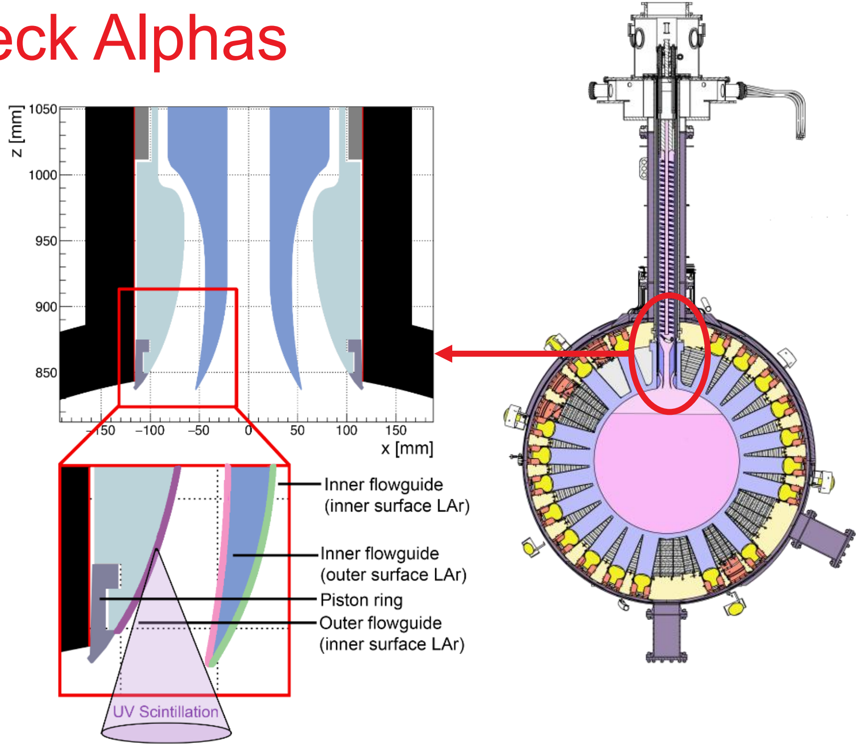
Backgrounds: Neck Alphas

- The next largest background in the WIMP ROI is from ^{210}Po α-decays produced in the neck of the detector. Due to the geometry of the neck most of the light coming from these events will be shadowed, allowing some of these events to fall within the energy range of the WIMP ROI.





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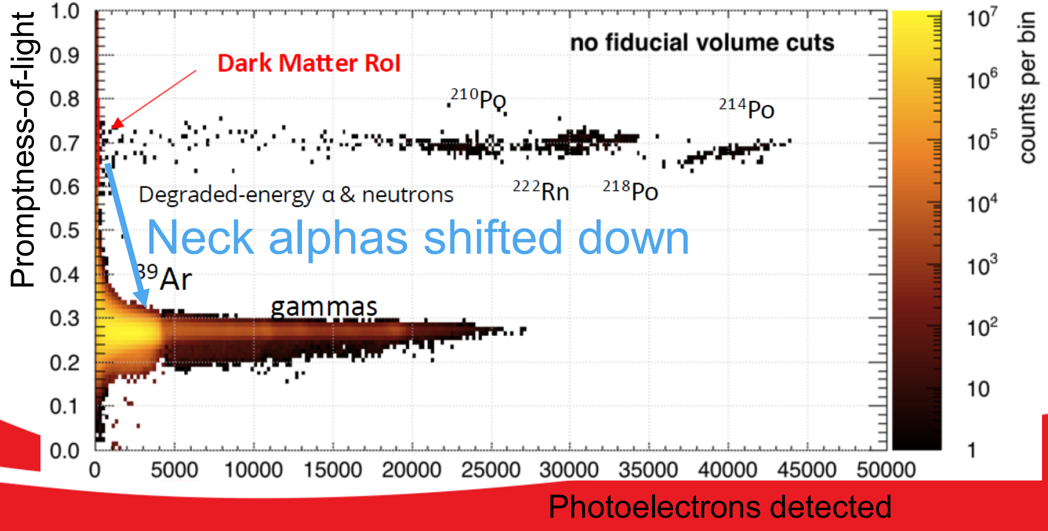
Upcoming: Detector Upgrades

- The DEAP-3600 detector has recently undergone a major upgrade. There are two main upgrades relevant for the WIMP search:
  - A dust pipe has been installed that will filter out metallic dust floating in the liquid argon.
  - The origin of neck alphas has been coated with a layer of pyrene, which will shift them down in promptness-of-light (below the WIMP ROI).



- The combined effect is that our two largest backgrounds will be removed from the ROI. Additionally, by investigating the regions with dust before and after the upgrades we can better understand our existing data.

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Conclusions

- A WIMP dark matter search using a profile likelihood ratio approach has been fully developed.
  - A likelihood function has been defined.
  - All models required for the likelihood have been developed. Notably, the dust and neck alpha backgrounds are better understood.
  - Results are under review by the DEAP collaboration.
- Detector upgrades are complete and data-taking will begin soon.
- The dominant backgrounds relevant for the WIMP search will be greatly reduced in our upcoming data.

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TRIUMF

Thank You!

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Backup – DEAP-3600 Detector